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THE LAST HUNDRED YEARS OF LAND USE HISTORY IN THE SOUTHERN PART OF VALDAI HILLS (EUROPEAN RUSSIA): RECONSTRUCTION BY POLLEN AND HISTORICAL DATA

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Abstract

The last one hundred years of land use history in the southern part of Valdai Hills (European Russia) were reconstructed on the base of high resolution pollen data from the peat monolith taken from the Central Forest State Reserve supplementing with historical records derived from maps of the General Land Survey of the 18th and 19th centuries and satellite images. According to the created age model provided by dating using radio-nuclides ^{210}Pb and ^{137}Cs, pollen data of the peat monolith allow us to reconstruct vegetation dynamics during the last one hundred years with high time resolution. The obtained data showed that, despite the location of the studied peatland in the center of the forest area and rather far away from possible croplands and hayfields, the pollen values of plants – anthropogenic indicators (*Secale sereale*, *Centaurea cyanus*, *Plantago*, *Rumex*, etc.) and micro-charcoal concentration are relatively high in the period since the beginning of the 20th century to the 1970s, especially in the peat horizon formed in the 1950s. In the late 1970s – the early 1980s when the pollen values of cereals gradually diminished in assemblages, the quantity of pollen of other anthropogenic indicators were also significantly reduced, which reflects the overall processes of the agriculture decline in the forest zone of the former USSR.

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Key words: pollen analysis, peatland, land use history, the Central Forest State Reserve

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INTRODUCTION

Reconstructions of human influence on land use and vegetation is an essential issue in the modern palaeoecological studies. Since the Neolithic epoch, the arable farming, grazing, trampling, etc., were key factors influencing the spatial vegetation distribution (Taavitsainen *et al.*, 1998; Vuorela *et al.*, 2001; Kalis *et al.*, 2003; Niinemets and Saarse, 2009; Gaillard *et al.*, 2010; Kirleis *et al.*, 2012). The most widely used approach for the qualitative interpretation of pollen assemblages in terms of past land-uses is the indicator species analyses (Behre, 1981; Vuorela, 1986; Ralska-Jasiewiczowa, 1977; Vorren, 1986; Koff and Punning, 2002; Zernitskaya and Mikhailov, 2009; Niinemets and Saarse, 2009; Josefsson *et al.*, 2014; Saarse *et al.*, 2010) as well as using relatively simple statistical models that relate percentages of arboreal and non-arboreal pollen to landscape openness (Frenzel *et al.*, 1992; Rösch, 1992; Broström *et al.*, 1998; Sugita *et al.*, 1999; Mitchell, 2005). The further advantage in reconstructions of land cover changes is the application of sophisticated models, such as the Landscape Reconstruction Algorithm (Sugita 2007), which were used to reconstruct regional and local vegetation dynamics in different regions of Europe during the Holocene (Gaillard *et al.*, 2008; Soepboer and Lotter, 2009; Nielsen *et al.*, 2012; Hultberg *et al.*, 2015).

A number of palaeoecological studies show the importance of adapting various historical data such as maps, chronicles, taxpayer lists, results of land survey and photographs together with proxy data from natural archives (Axelsson *et al.*, 2002; Veski *et al.*, 2005; Glaser and Riemann, 2009; Mazier *et al.*, 2015) for land-use history reconstruction. The majority of these studies are focused on densely inhabited European regions where landscapes were strongly transformed by human activity over a hundred years. At the same time, in the area of the boreal forest

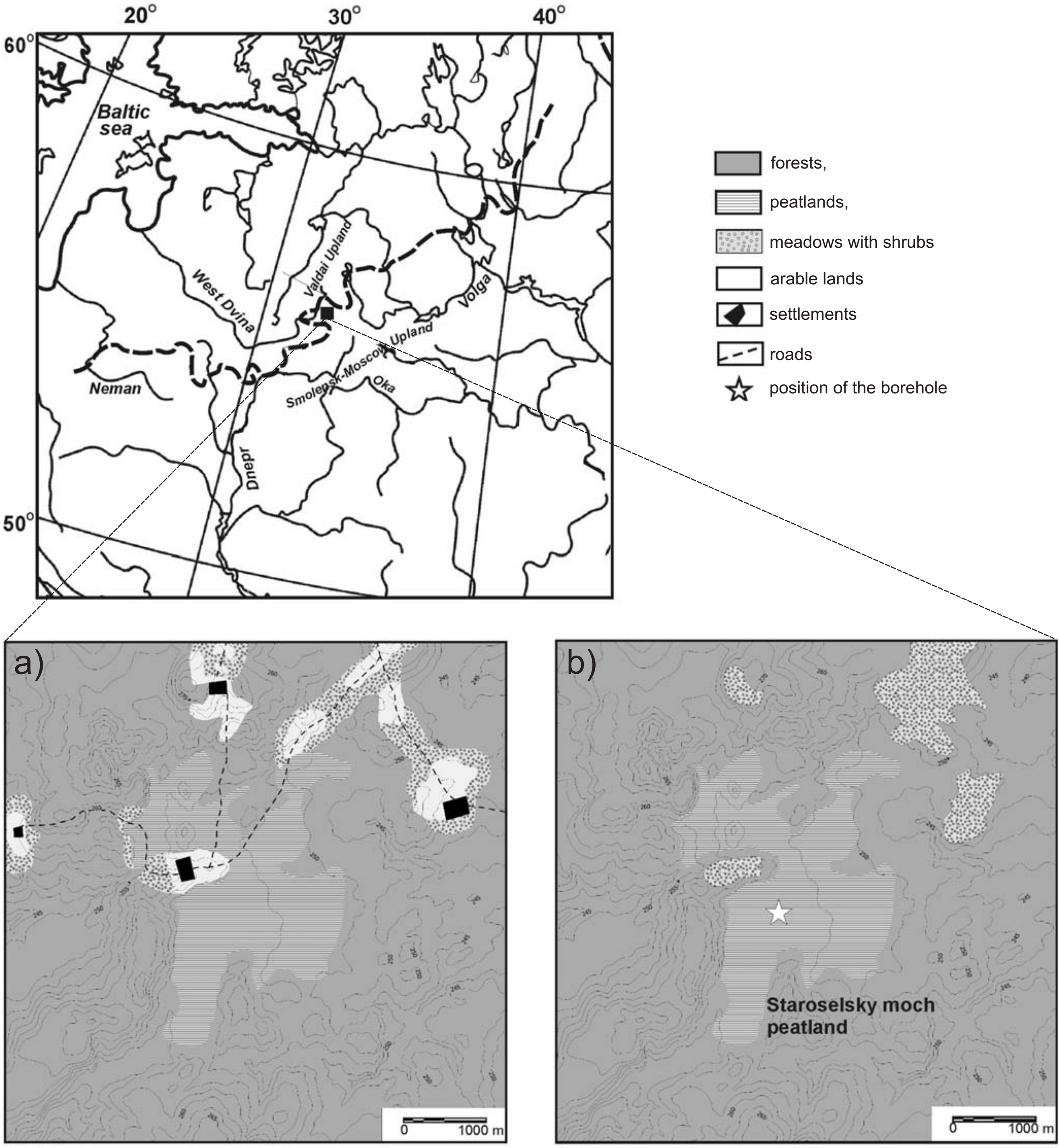

Fig. 1. Location of the study area and land use structure at the end of 19th – beginning of the 20th centuries (a) and at present (b).

with low human impact, records about human-vegetation relationship become scarce, the pollen evidence becomes weaker and more controversial (Hicks and Birks, 1996).

The area of the Central Forest State Natural Biosphere Reserve (CFSNBR) located in the southern part of the Valdai Hills has been chosen as a key region to study land use history in the central part of European Russia (Fig. 1). The place encompasses an extensive area of wetlands and low soil fertility, a situation far away from the main agricultural markets and industrial centers, a status as the state boundary during the relatively long period, weak developments of roads created difficulties for agricultural land use in the territories. As a result, human impact on landscapes has been very low for a long time (Novenko *et al.*, 2009), which allowed us to study human activity in the relatively undisturbed forest region.

The Holocene history of vegetation and land use of the Valdai Hills was intensively investigated in a wide range of palaeogeographical studies (Karimov and Nosova, 1999; Minayeva *et al.*, 2008; Novenko *et al.*, 2009; Payne *et al.*, 2016; Olchev *et al.*, 2017). The present studies are based on high-resolution pollen sequences and historical maps for the last centuries. The aim of this paper is simultaneous analysis of recent land use in the Central Forest Biosphere Reserve by historical and pollen data and an identification of fine-scale human impact by changes in pollen assemblages.

Pollen data and age-depth model for peat core used in present studies have already been partly presented by Olchev *et al.* (2017) in the study focused on the analysis of relationships between pollen accumulation rates of woody taxa and selected herbaceous plants with local climate conditions. The complete pollen data have not been published.

THE HISTORY OF LAND USE AND POPULATION OF THE TERRITORY

Archeological findings within the CFSNBR are not yet known. In the historical chronicles of X–XII centuries, the area occupied by the Reserve nowadays was mentioned as a part of a vast, pathless forest, the massive "Okovsky Forest" (Karimov and Nosova, 1999). By this time, the territory, at least for some centuries, was settled by East Slavic tribes, expelling and assimilating the Ugro-Finnic population.

According to historical records, since the beginning of the XIV century and until the Russian-Polish War in 1654–1667, the area of the Reserve during several long periods was located near the state border (Krom, 1995; Khitrov and Pakhunov, 2013). In this region the state matters of the Grand Principality of Lithuania, Muscovy and Poland collided and the territory repeatedly passed into the possession of one or the other state (Dumin, 2010). In the first decades of XVII century (so called "Time of Troubles"), marked by several natural disasters, civil war, Polish-Swedish intervention in Russia and political and socio-economic depression, the area of the CFSNBR was a place of severe warfare, and it was repeated in the 1650s, when Russia managed to finally move the border to the west. These led to the depopulation of the area and the decline of the economy and agriculture (Florja, 1998).

In XVIII century, European Russia was characterized by rapid growth of its economy and population. Maximum anthropogenic activity in the Tver' region occurred in the second half of the XVIII century (Borisenkov and Pasetski, 2002). The area of arable land and hayfields in the land-use structure reached its highest level. According to the economic notes to the General Land survey, the area of arable lands in 1780 reached 15% (Karimov and Nosova, 1999). The density of the population grew up to 5 peoples/km^2, while in other parts of the Tver' region its value exceeded 10 people/km^2.

The potential limit for agricultural expansion was reached in the XIX century and after that the agriculture gradually declined. The arable land was replaced mainly by forests. The hard limitation of agriculture in the region due to an extensive area of wetlands and clayey poor soil was supplemented with a lack of hays and green fodder for cattle that supplied the main source of organic fertilizer for arable lands. As a result of natural conditions and historical processes, a structure of land use and settlements in the area of the CFSNBR was characterized by a complex pattern including vast areas of forests and wetlands interspersed with small inhabited and plowed lands.

MATERIALS AND METHODS

Peat core sampling and age-depth model

A peat monolith with a thickness of 65 cm was taken using a Wardenar' peat profile sampler during the field campaign in August 2013. The monolith consisted completely of low decomposed (7–10%) cottongrass-sphagnum peat. The peat block was continuously sliced into samples with 1 cm thickness.

The age-depth models were based on radio-nuclides ^{210}Pb (a constant rate of supply modeling and linear regression model) and a measurement of ^{137}Cs (Fig. 2) (Olchev *et al.*, 2017). According to these data, the age of the lowermost sample of the peat monolith is about 1912 AD. Each sample within the uppermost 10 cm of peat profile corresponds to 1 year of sediment accumulation, and at the depths between 10 cm and 65 cm time resolution increased to several years.

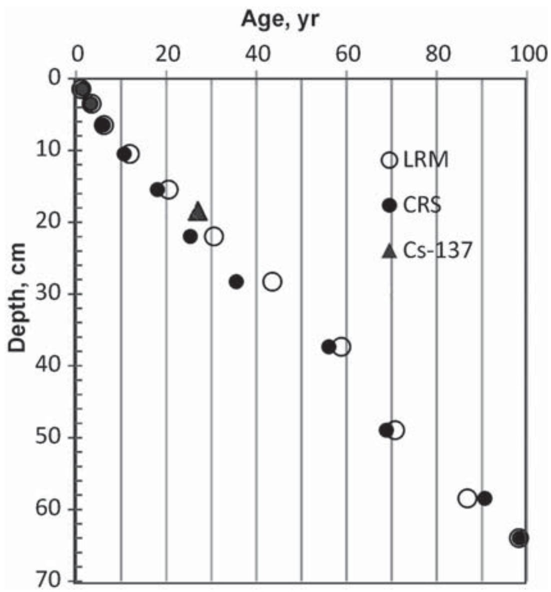

Fig. 2. Age-depth model of the peat monolith from the Staroselsky peat bog, calculated with Linear Regression Model (LRM) and Constant Rate of Pb-210 Supply model (CRS); triangle indicates a maximum of ^{137}Cs activity, corresponding to the Chernobyl fallout (after Olchev *et al.*, 2017).

Pollen analysis

Samples for pollen analysis were prepared using the pollen extraction procedure developed by Moore *et al.*

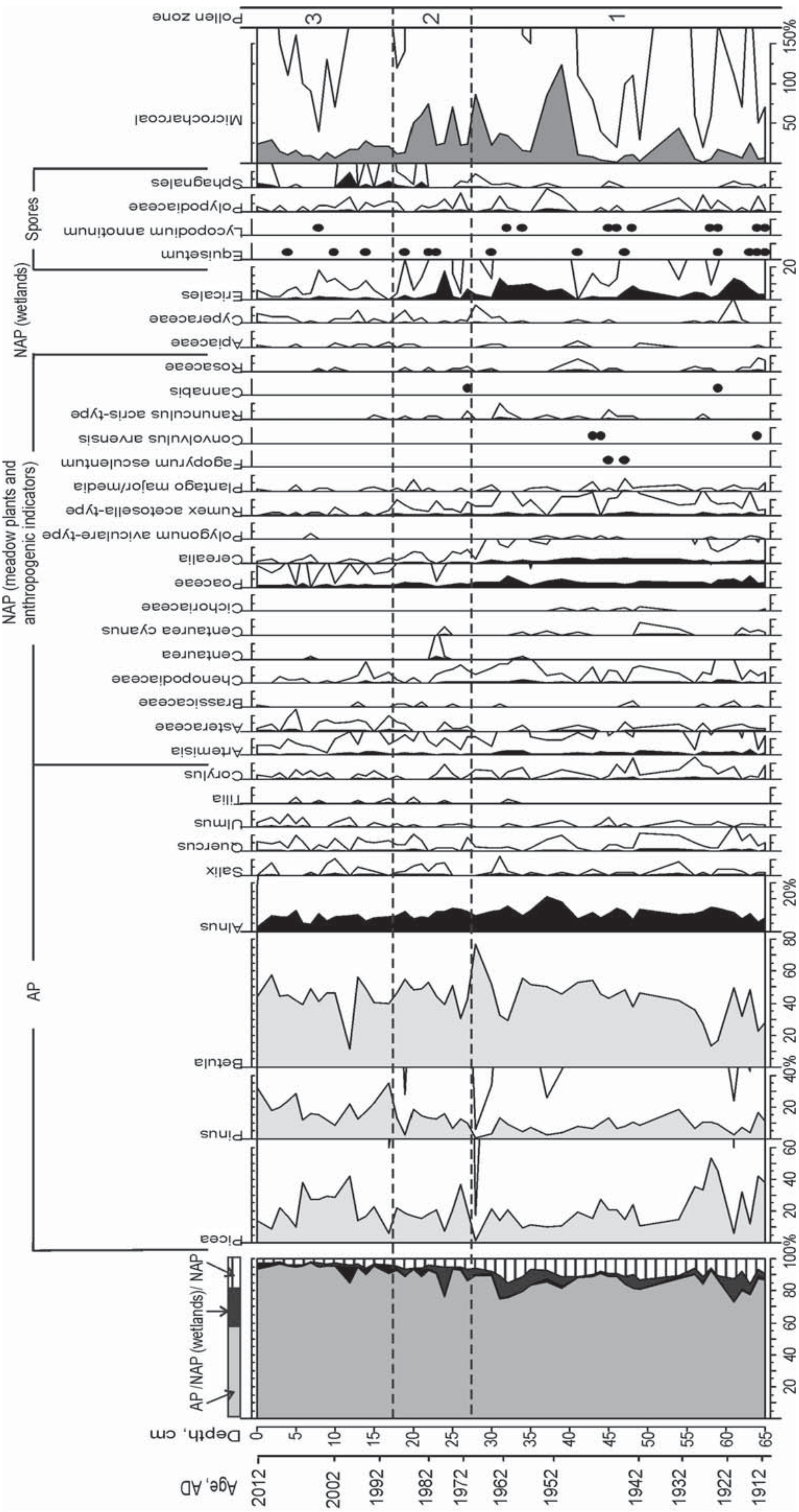

Fig. 3. Pollen diagram of the peat-monolith from the Staroselsky peat bog. Pollen sum: AP+NAP; additional curves represent x10 exaggeration of base curves.

(1991). The treatment included heating for 10 min in 10% KOH to remove humic material, followed by acetolysis in a water bath for 5 min to dissolve the cellulose. Calculation of relative pollen frequency is based on the total terrestrial pollen sum, arboreal pollen (AP) plus non-arboreal pollen (NAP). Spores were excluded from the pollen sum. A minimum of 500 pollen grains per sample was counted (AP+NAP). Morphological determinations of pollen were carried out according to Reille (1992), Beug (2004) and the reference pollen collection of the Institute of Geography of the Russian Academy of Science. In order to determine pollen and charcoal concentrations, *Lycopodium* tablets were added to each sample (Stockmarr, 1971). Pollen diagrams were constructed using Tilia 2.0.2 and TGView programs (Grimm, 1990).

The determined herbaceous pollen taxa were grouped into two main categories (Fig. 3). The first group comprises land use indicator plants following Behre (1981), Berglund *et al.* (1986) and Koff and Punning (2002) that includes pollen indicating arable land (Cerealia, *Fagopyrum esculentum*, *Cannabis*, *Centaurea cyanus*, *Convolvulus*), ruderal communities (Chenopodiaceae, *Artemisia*, *Plantago major/media*, *Polygonum aviculare*-type and *Rumex acetosella*-type pollen) and pasture lands and meadows (Poaceae, Caryophyllaceae, Asteraceae, Cichoriaceae, Fabaceae, Rosaceae, Ranunculaceae, Rubiaceae). The second group is called NAP (wetlands) and includes pollen produced by local swamp vegetation. At the sampling point, they belong mainly to Apiaceae, Cyperaceae and Ericaceae families.

Microscopic charcoal concentrations were assessed following Clark's point-count methodology (Clark, 1982). At least 200 items (the sum of charcoal particles and *Lycopodium* spores) were counted (Finsinger and Tinner, 2005).

Historical maps

The reconstruction of the land use from the beginning of 20th century is based on the data of the General land survey that is kept in Russian State Archive of Ancient Acts (http://rgada.info/mende/rgada_svg.php). These maps have a scale of 1:8400 and are allowed to describe the former land cover proportions with relatively high accuracy (Kusov, 2004). The old maps were digitized and georeferenced (Matasov, 2016) to fit topographic maps and remote sensing data that are available for the area of the CFSNBR. Stand delineation within the study area was digitized using MapInfo. Different land-use categories were reclassified and unified into four categories: forests, arable lands, meadows with shrubs and settlements. The roads connecting villages were also shown (Fig. 1a).

The map of the modern land cover (Fig. 1b) was compiled using topographic maps with a scale of 1:10000, remote sensing images as Spot 5 (2011), Landsat 5,7 (2000 and 2015, respectively). They are also georeferenced and combined in the integrated GIS.

RESULTS

Pollen data

Pollen assemblages of the peat monolith are characterized by a high amount of tree pollen (75–90%); among them, *Betula, Picea, Alnus* and *Pinus* are abundant (Fig. 3). The amount of birch pollen in the monolith is very high – up to 30–40%, and it forms a noticeable peak at a depth of 27 cm. The amount of *Picea* and *Pinus* pollen varied from 2–10% to 50–60% and 30–40%, respectively. The proportion of *Alnus* pollen does not exceed 12%. Pollen of broadleaf trees (*Tilia, Ulmus, Quercus*) occurred in small quantities (1–2%); pollen of shrubs, such as *Salix* and *Corylus*, was rarely detected.

Pollen assemblages include a number of non-arboreal pollen; among them, Ericaceae, *Artemisia* and Poaceae are the most frequent. The total amount of spores does not exceed 10% of the entire peat monolith. Spores are represented mainly by *Sphagnum* and Polypodiaceae (5–7%). A series of peaks of *Sphagnum* spore value (up to 10%) and their concentration are recorded in the upper part of the peat monolith.

Pollen of anthropogenic indicators is a permanent component of pollen assemblages. According to changes of its amount pollen diagram was divided into 3 pollen assemblage zones corresponding to phases of intensity of human impact.

In pollen zone 1 (65–27 cm, 1912–1970 AD), pollen values of anthropogenic indicators varied between 15 and 25%. Cerealia pollen forms a continuous curve, reaching 2–5% in the lower part of the pollen zone; pollen of cultivated plants such as *Fagopyrum esculentum* and *Cannabis* and weeds (*Centaurea cyanus*, *Convolvulus arvensis*) is recorded. Pollen of plants typical for ruderal communities (Chenopodiaceae, *Artemisia, Plantago major/media, Polygonum aviculare*-type, *Ranunculus acris*-type and *Rumex acetosella*-type pollen) and ruderal and pasture lands and meadows (Poaceae, Caryophyllaceae, Asteraceae, Cichoriaceae, Fabaceae, Rosaceae) are frequent (Fig. 3). The highest pollen concentration of Cerealia and ruderal plants is recorded in the depth 42–35 cm (1947–1955 AD).

In pollen zone 2 (27–17 cm, 1970–1989 AD), a clear decrease in pollen percentages and concentrations of cereals and ruderal vegetation is detected. The share of Cerealia pollen decreased to 1–1.5%. In the uppermost 17 cm (pollen zone 3, 1989–2012 AD) of the peat monolith, the share of plants–anthropogenic indicators decreased to 5–7%; pollen concentration of these taxa is low. The proportion of Cerealia did not exceed 0.5%.

The whole peat monolith comprises a high amount of micro-charcoal particles. An increase of their proportion is recorded for the depth 55–50 cm, 1930–1940 AD (about 50% in comparison to the sum of AP+NAP). Micro-charcoal particles are the most abundant in the interval 40–20 cm (1947–1985 AD), reaching their maximum values (up to 150%). In the upper part of peat monolith, both the proportion and concentration of charcoal are drastically decreased.

Historical data

The reconstructions of land use at the end of the XIX centuries show that the study area in that time was inhabited and cultivated (Fig. 1a). There are four villages surrounded by arable lands and meadows; these covered 5% and 4% of the area, respectively. However, the human impact was relatively low. Forests occupied about 82% of the territory. The Staroselsky peat bog is shown as a forest in the map of the General land survey. Obviously, the mire areas were covered by pine woodland.

Analysis of the recent map of modern land cover demonstrates that the forest area is increased to 89% and peatlands cover 13% (Fig. 1b). Villages are abandoned, and roads disappear. The arable lands transformed to meadows with shrubs (5%). During our field studies, we visited the places of former settlements and did not find any signs of dwellings or gardens with the exception of the village of Staroselie where one partly destroyed house still existed. According to interviews with the local people, arable lands were cultivated until 1980s, but the total decline of the economy and agriculture took place after 1990s.

DISCUSSIONS

High-resolution pollen data from the peat monolith from the Staroselsky Moch peat bog and obtained historical data allow us to describe land use changes in the study area during the last 100 years. According to the intensity of human impact on the study area, three time intervals were determined (Fig. 4):

1) 1912 – the 1970s AD, moderate human impact (settlements, arable lands and cattle breeding);

2) the 1970s – the 1990s AD, low human impact (decrease in agricultural activity in the area);

3) the 1990s – 2012 AD, no direct human impact (abandonment of villages).

The first rather long periods were divided into three subphases; these corresponded to the time interval before World War II (1a), the period during the war (1b) and economic recovery after it (1c, Fig. 4).

These phases were distinguished on the basis of AP/NAP ratio (Frenzel *et al*., 1992; Rösch, 1992), indicator species (Behre, 1981) and changes in the composition of herbaceous pollen (Koff and Punning, 2002). The commonly used criteria such as proportion of *Picea*, broadleaved trees and *Betula* pollen in assemblages (Ralska-Jasiewiczowa, 1977) could not be applied for our study. As indicated in the study provided by Olchev et al (2017), variations in *Picea* and *Betula* pollen values with duration from several years to a decade in the CFSNBR during the last 100 years were caused by changes in pollen productivity of trees mainly due to climatic reasons.

At the beginning of the XX century, the study area was relatively densely inhabited. In spite of unfavorable conditions for agriculture (Novenko *et al*., 2009) the territory was actively used for farming and grazing. The Russian Revolution in 1917 eventually led to the formation of the Soviet Union in 1922, in turn triggering a phase of collectivization and industrialization in agriculture with the goal of increasing agricultural production. The share of cereals in pollen assemblages of that time reached 5%, pollen of probably cultivated plants – *Fagopyrum esculentum* and *Cannabis sativa* – was recorded, designating an existence of arable lands adjacent to the peat bog (Koff and Punning, 2002). According to the historical data (Fig. 1a), arable lands occupied 5% of the studied area and were located around villages. The presence of typical weed plants in pollen assemblages, such as *Convolvulus arvensis* and *Centaurea cyanus,* is typical for permanent farm fields (Vuorela *et al*., 2001; Zernitskaya and Mikhailov, 2009). The reliable diagnostic sign of human impact on vegetation in studied pollen assemblages is the appearance of species indicating trampling or grazing (Berlund *et al*., 1986): *Polygonum aviculare, Plantago major/media*, pasture lands (*Rumex acetosella*, *Ranunculus acris*), Cichoriaceae, Rosaceae and plants of ruderal communities, such as Artemisia, Asteraceae and Chenopodiaceae. It should be noted that, in the flora of the CFSNBR in the Chenopodiaceae family, only *Chenopodium album* and *Ch. rubrum,* the ruderal species, are present (Minyaev and Konechnaya, 1976). A relatively high amount of herbaceous plants with wide ecological requirements but in forest vegetation zone mainly typical for meadow communities such as Poaceae, Rosaceae, Brassicaceae, suggested the existence of meadows and hayfield, the share of which in the early 20th century was 4%. An increase of micro-charcoal concentration in peat formed in 1930–1940s AD, obviously, reflected the beginning of brown coal mining of the Moscow coal basin in the vicinity of the town of Nelidovo, located about 40 km south of the CFSNBR, and use of brown coal as a fuel.

World War II (1941–1945 AD) led to a drastic disruption of the economy and agriculture in the country, followed by the need to restore the economy after the war. In the peat formed during the first decade after World War II, pollen values of anthropogenic indicators reached the maximum for the entire period (Fig. 4). The input of coal particles decreased significantly during the war, but at the beginning of the 1950s its concentration grew in order of magnitude.

Agricultural land use in the former Soviet Union expanded in the 1950s and 1960s; during the next period (1965–1980) the government policy to agricultural intensification and concentration led to the abandonment of marginal areas like the Central Forest State Reserve (Blinnikov, 2011). The share of anthropogenic indicators in pollen assemblages and primarily that of Cerealia has gradually decreased since the 1970s. The local population either engaged in forestry in non-protected territories around the CFSNBR or moved to work in the brown coal mines; however, agriculture in the vicinity of the settlements was still maintained.

The breakup of the Soviet Union in 1991 and the subsequent transition to market economy affected agriculture in the region markedly. Formerly guaranteed markets and state subsidies disappeared, agricultural institutions were overhauled, and agricultural land was privatized (Ioffe and

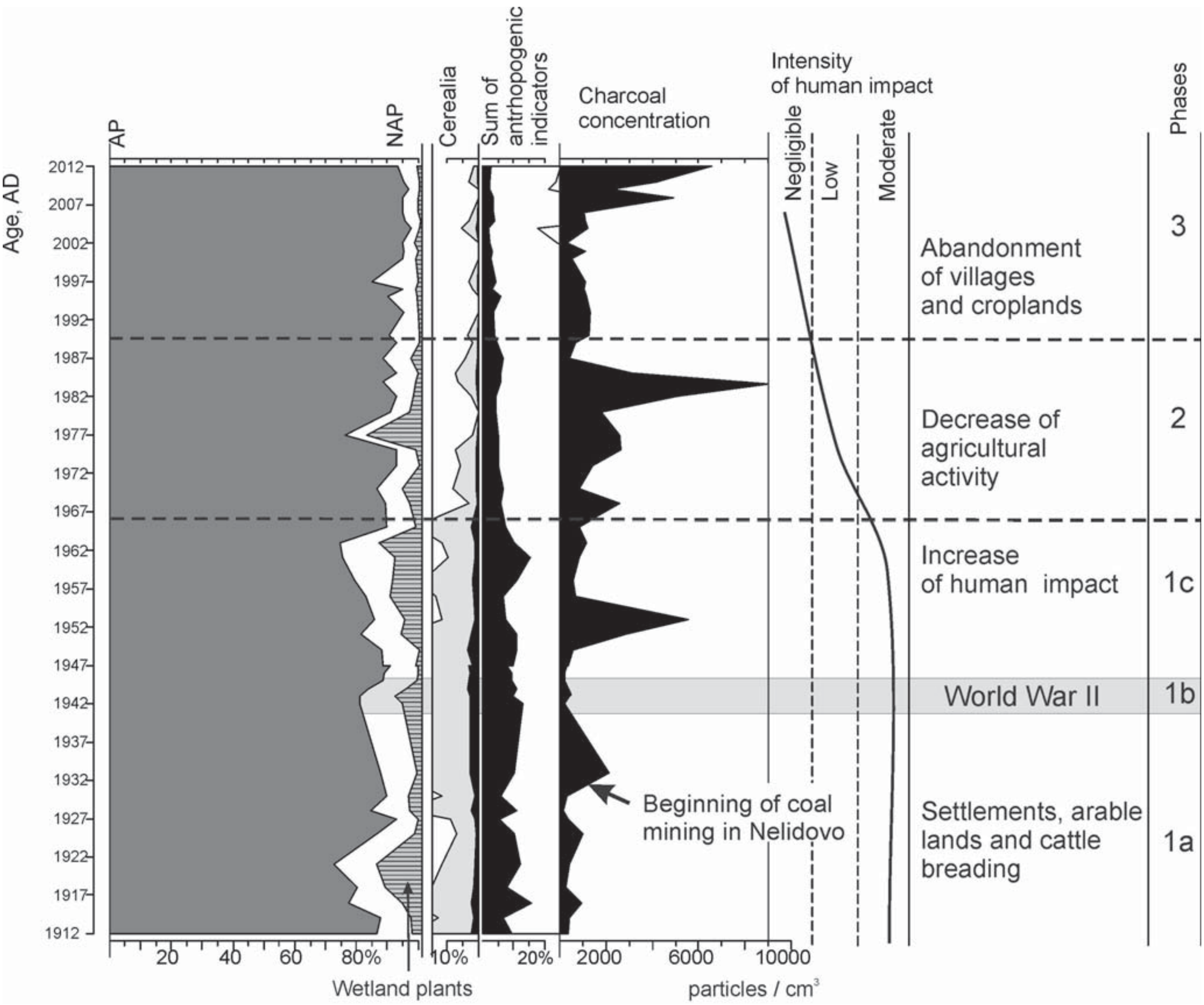

Fig. 4. Summary of the results of pollen analysis of the peat-monolith from the Staroselsky peat bog and phases of the intensity of human impact on the surrounding area. Cerealia pollen curve is shown with additional counter represents x10 exaggeration of the base curve.

Nefedova, 2004; Lerman *et al.*, 2004; Kuemmerle *et al.*, 2015), together resulting in drastic production declines and widespread agricultural abandonment (Prishchepov *et al.*, 2012; Schierhorn *et al.*, 2013). While some of the abandoned lands in European Russia were recultivated after 2000 AD due to growing support for agriculture from several government programs, much of the former agricultural land remains abandoned and is gradually returning to forest (Hansen *et al.*, 2013; Sieber *et al.*, 2013; Kuemmerle *et al.*, 2015). Nowadays, agriculture in the region of the CFSNBR located far from main roads and industrial centers is economically unprofitable. At the beginning of the 21st century, most of the villages were abandoned, the total population fell by 5–10 times. Of the 180 villages in the area included in the modern boundaries of the CFSNBR and adjacent territories shown on the map at the early 20th century as inhabited, only 30 are still existing.

The modern land cover of the study area is represented by forest, peatland and meadows with shrubs (Fig. 1b). Since the 1990s the share of non-arboreal pollen in assemblages has become low. Pollen of cultivated plants, with the exception of cereals, and weed disappeared completely. The Cerealia pollen values (mainly wind pollinated *Secale cereale*) do not exceed 0.5%. According to Koff and Punning (2002), cereal pollen less than 2% could be assumed as regional background pollen influx. The decrease of the farm economy in the region led to a change in water balance that could be a reason for the active wetland development marked by high peaks of *Sphagnum* spores in the upper part of the peat profile. Moreover, intensive forest paludification and wetland growth might be induced due to climate warming and increase of humidity during the 20th century (Desherevskaya *et al.*, 2010).

The noticeable decrease in micro-charcoal values in peat indicates a decline of the brown coal industry in the region due to the economic crisis in the country. In the early 1990s, coal mines were closed and flooded by water, and today there are no active brown coal mines in the region.

Micro-charcoal particles contained in the upper horizons of peat probably came from old anthracite dumps which are abundant around the town of Nelidovo.

CONCLUSIONS

The new pollen and historical records from the Central Forest State Reserve provide important data about vegetation development and land use of the study area. According to obtained results, during the last 100 years, the area of the CFSNBR was covered by forests and human activity was low; the share of cultivated lands did not exceed 5%. The obtained data showed that despite the location of the studied peatland in the center of the forest area and rather far away from possible croplands and hayfields, the pollen values of plants – anthropogenic indicators (*Secale sereale, Centaurea cyanus, Plantago, Rumex,* etc) – and micro-charcoal concentrations were relatively high in the period when the study area was inhabited and cultivated and significantly diminished since the 1990s when the area became abandoned.

The pollen data demonstrated that pollen assemblages are able to reflect this weak human impact on vegetation, and even fine-scale land use changes are traced in the composition of pollen spectra. The decadal-scale vegetation response to human-induced forcing agrees with historical maps and documents and can be used to reconstruct past landscapes prior to the time for which solid historical data are available. The obtained results show that pollen data could be successfully applied for reconstructions of interrelationships between prehistoric groups of people and the environment in the initial phases of human settlements.

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